EP0548932

Title:
Surface layer forming process using electric discharge machining.

Abstract:
An apparatus and process for forming surface layers on electrodes by electron discharge machining. A machining gap (7) , between an electrode (4) and a workpiece (5) is filled with a dielectric mixture containing metallic or submetallic powder. The apparatus uses a swinging mechanism to move the electrode (4) during processing. The apparatus uses a high-voltage superposition circuit to superpose a voltage of 100-400 V across the gap (7). The apparatus uses a current limiting resistor (R2) of 100-300 OMEGA to ensure that the main circuit supplies a low voltage of approximately 100 V to the machining gap (7).

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 548 932 A1**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **92121827.7**

(22) Date of filing: **22.12.92**

(51) Int. Cl.⁵: **B23H 1/00**, B23H 1/08, B23H 1/02

(30) Priority: **25.12.91 JP 357138/91**

(43) Date of publication of application: **30.06.93 Bulletin 93/26**

(84) Designated Contracting States: **CH DE LI**

(71) Applicant: **MITSUBISHI DENKI KABUSHIKI KAISHA**
2-3, Marunouchi 2-chome Chiyoda-ku
Tokyo 100(JP)
Applicant: **Mohri, Naotake**
661-51, Yagotoishizaka, Tenpaku-ku
Nagoya-shi, Aichi 468(JP)

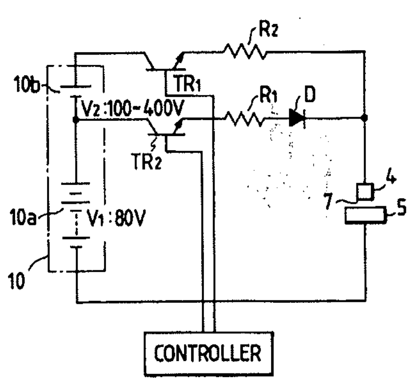
(72) Inventor: **Saito, Nagao, c/o Mitsubishi Denki K.K.**
2-3, Marunouchi 2-chome
Chiyoda-ku, Tokyo 100(JP)
Inventor: **Magara, Takuji, c/o Mitsubishi Denki K.K.**
Nagoya Seisakusho, 1-14, Yadaminami 5-chome
Higashi-ku, Nagoya-shi, Aichi 461(JP)
Inventor: **Mohri, Naotake**
661-51, Yagotoishizaka, Tenpaku-ku
Nagoya-shi, Aichi 468(JP)

(74) Representative: **Lehn, Werner, Dipl.-Ing. et al**
Hoffmann, Eitle & Partner Patentanwälte
Arabellastrasse 4
W-8000 München 81 (DE)

(54) Surface layer forming process using electric discharge machining.

(57) An apparatus and process for forming surface layers on electrodes by electron discharge machining. A machining gap (7) , between an electrode (4) and a workpiece (5) is filled with a dielectric mixture containing metallic or submetallic powder. The apparatus uses a swinging mechanism to move the electrode (4) during processing. The apparatus uses a high-voltage superposition circuit to superpose a voltage of 100-400 V across the gap (7). The apparatus uses a current limiting resistor (R2) of 100-300 Ω to ensure that the main circuit supplies a low voltage of approximately 100 V to the machining gap (7).

FIG. 2



EP 0 548 932 A1

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an electric discharge machining (EDM) process for forming a surface layer having a mirror-finish on a workpiece. Particularly, it relates to a process for forming a surface layer by electric discharge machining, which provides a finely-machined surface of improves the surface's resistance to corrosion and wear by promoting discharge dispersion at the surface of a workpiece material and conducting surface treatment of the workpiece during the EDM process.

2. Description of the Background Art

A process is known (see Published Unexamined Japanese Patent Application No. 24916/1987) in the art of electric discharge machining which uses an electrode formed of a submetal material (i.e., a semiconductive material), such as silicon. During EDM, the submetal electrode forms a solid surface layer that is not susceptible to aqua regia and is difficult to damage, e.g., it is not spillable or easily cracked when subjected to several tons of force. This know process employs an ordinary electric discharge machining system with s submetal electrode, conducting machining on a workpiece made of SUS304 (18Cr-8Ni stainless steel), 13Cr steel or high-speed steel. A highly corrosion-resistant surface is formed on the surface of the SUS304, 13Cr steel or high-speed steel by carrying out such machining for several minutes to several hours.

Further, a mixture of metallic or submetallic (semiconductor) powder having average grain size 20 to 40 μm is added into a machining fluid with the particles of 20 g per liter to improve the stability of discharge. Moreover, degree to which the mixture enhances the mechanical properties (e.g., corrosion resistance and wear resistance) of the electrode and workpiece surfaces depends on the material being mixed in. It is thus possible to employ the electric discharge machining process for the surface treatment of metal, in addition to its conventional use in metal removal. The type of powder material used is for example, a semiconductor material such as silicon.

The operation of a conventional electric discharge machining apparatus will be described with reference to Figs. 1(a) and 1(b). Fig. 1(a) shows the apparatus in a non-machining mode and Fig. 1(b) shows the apparatus in a machining mode. As shown, an electrode 4 and a workpiece 5 are positioned in a machining tank 6, with the workpiece 5 are positioned in a machining tank 6, with the workpiece 5 and the electrode 4 forming a machining gap 7. A dielectric machining fluid 8 in the machining tank 6 includes a silicon powder 9. A power supply unit 10 is used for supplying machina energy to the machining gap 7, and a pneumatic pump 11 is used for agitating the dielectric machining fluid 8 by feeding air into the machining tank 6. A hydraulic cylinder device 12 is used for vertically moving the electrode 4 toward and away from the workpiece 5, with a piston rod 13, and a servo unit 14 is used for controlling the hydraulic cylinder device 12.

As mentioned above, in the apparatus thus constructed, the machining solution is mixed with the silicon particles 9 having an average grain size of approximately 20 to 40 μm with a silicon particle mixture ratio of approximately 20 gr/ℓ of machining solution. The pump 11 supplies air to agitate the machining solution 6, thereby preventing the deposition of the silicon particles. As shown in Fig. 1(a) and Fig. 1(b), the electrode is automatically intermittently moved up and down, so that the decomposition from the machining solution and the sludge, which are formed by electric discharge, are not accumulated in the discharge gap 7 (i.e., they are diffused therein). the air pump 11 may be replaced with a machining solution circulating pump. The electrode is formed of copper and graphite.

In general, a high-voltage superposition circuit is employed as the machining power supply. As the voltage of the high-voltage superposition circuit becomes larger, cracking and/or pitting occur less in the workpiece surface. Further, if silicon powder is present in the machining gap, an electrical spark is generated more easily over a longer machining gap distance, even if the applied voltage remains constant. However, applying a higher voltage will further stabilize machining. The corrosion and wear resistance of a workpiece machined in such a manner improves considerably.

The superposition of a voltage of approximately 100 to 400 V has been shown to stabilize machining and suppress occurrence of cracking and pitting. This leads to a considerable improvement in corrosion resistance and wear resistance. Moreover, surface roughness is also reduced. However, the powder material breaks down during discharge operations and will usually reach its life expectancy after about 100 to 200 hours of use.

In addition, while the mixture of the powder suppresses cracking and pitting, enhances corrosion and wear resistance, and reduces surface roughness, these effects are not consistently reproducible under any

given machining condition. Specifically experiments have shown that the mixture of the powder enhances the above noted effects by a greater amount when the applied voltage is low. The effects decrease abruptly when the voltage moves beyond a certain applied voltage. more specifically, the surface roughness increases greatly as the applied voltage increases.

SUMMARY OF THE INVENTION

Accordingly, an object of the invention is to solve the problems accompanying a conventional method and apparatus of forming a strong surface on a workpiece by electric discharge processing.

More specifically, an object of the invention is to provide a surface layer forming process using electric discharge machining techniques which reduce surface roughness sharply and maintain consistent machining characteristics for a longer period of time, while maintaining the machining stability and capability.

Another object of the invention is to provide a surface layer forming process using electric discharge machining techniques which enhances the effects of a powder mixture such as by reducing the surface roughness and maintaining constant machining characteristics for a longer period of time, while maintaining the machining stability and capability.

The above objects and other objects of the invention have been accomplished by the provision of an electric discharge machining apparatus for forming a surface layer on a workpiece comprising an electrode positioned near the workpiece, wherein a machining gap is formed between the electrode and the workpiece, said machining gap containing a dielectric mixture, which includes one of a metallic and submetallic powder, a main power supply circuit for supplying a low voltage to the machining gap, and a high-voltage superposition circuit for superposing a high voltage on said main circuit, in order to generate an electric spark in the machining gap and in the dielectric mixture.

The embodiment of the invention provides a surface layer forming process by electric discharge machining which prevents cracking by dispersing discharge throughout the machining gap. The invention also reduces surface roughness and maintains constant machining characteristics for a longer time period, while simultaneously maintaining the machining stability and capability. According to this embodiment, a workpiece is machined in the machining gap formed between an electrode and the workpiece and surrounded with dielectric fluid mixed with metallic or submetallic powder, by supplying a discharge current that will not cause cracking during a single electric spark.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrated presently preferred embodiments of the invention and, together with the general description given above and the detailed description of the preferred embodiments given below, serve to explain the principles of the invention. In the accompanying drawings:

Figs. 1(a) and 1(b) are schematic diagrams illustrating the arrangement of an apparatus for practicing an example of a method of forming a surface layer by an ordinary electric discharge machining;

Fig. 2 is a circuit diagram showing an embodiment for a high voltage superposing circuit for the present invention;

Fig. 3(a), 3(b) and 3(c) are graphical representations indicating the degrees of machining stability with discharge start voltages for the circuit of Fig. 2;

Fig. 4(a) is a relation between an auxiliary power supply current value and the surface roughness of the workpiece;

Fig. 4(b) is a current pulse applied to the electrode;

Fig; 5(a) shows a model RC-circuit that represents the RC characteristic of the embodiment of Fig. 2 of the present invention;

Fig. 5(b) shows the machining gap voltage response achieved by the RC-circuit in Fig. 5(a);

Figs. 6(a) and 6(b) indicate a relationship between a current limiting resistance of the auxiliary power supply and surface roughness according to the embodiment of Fig. 2 of the present invention;

Fig. 7 illustrates how cracking occurs in response to a single electric spark according to the invention;

Figs. 8(a) and 8(b) illustrate how cracking occurs in response to continuous electric sparks in accordance with the invention;

Figs. 9(a) and 9(b) indicate relationships between charging resistance and the depth and thickness of cracking;

Figs. 10(a) and 10(b) are photos of a machined surface showing the results of electric discharge machining under electrical conditions of medium degree according to the present invention;

Figs. 11(a) and 11(b) are photos of a machined surface showing the results of electric discharge machining using dielectric mixed with powder according to the present invention; and

Fig. 12 illustrates a high-voltage superposition circuit employed as a machining power supply according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of the present invention for carrying out the surface layer forming process of the invention will be described with reference to the drawings.

As is similar to the conventional apparatus shown in Figs. 1(a) and 1(b), the workpiece 5 and the electrode 4 are placed in the tank 6 to form the machining gap 7, and the machining is carried out with the machining solution 8 containing the mixture of silicon powers 9 in the machining gap 7.

Fig. 2 is a circuit diagram showing a high-voltage superposition circuit used as a machining power supply. The superposition circuit includes current limiting resistors R1 of approximately 10 to 20 Ω and R2 of approximately 100 to 300 Ω, a diode D, transistors TR1 and TR2 and a power source 10. The power source 10 is composed of a main power source 10a of approximately 80 V and an auxiliary power source 10b of approximately 100 to 400 V.

During machining, the auxiliary power supply 10b supplies a high voltage of 180 to 500 V to the machining gap 7. Particularly, during machina, transistor TR1 is switched On to force the auxiliary power supply 10b to supply a high voltage to the machining gap 7 to produce an electric spark. Transistor TR2 is then switched on to force the main power supply 10a to supply a discharge current which lasts for several micro-seconds (μsec). The duration of the discharge is determined by the limiting resistor R1. Since the applied voltage is high, the machining gap may be expanded while maintaining extremely stable machining. the results of experiments on machining stability by the application of a high voltage are shown in Figs. 3(a) to 3(c).

Figs. 3(a)-3(c) show the degrees of stability in electric discharge machining operations carried out with the voltage of the auxiliary power unit changed with the high voltage superposing circuit of Fig. 2.

Fig. 4(a) shows a relationship between the current level provided by the auxiliary power supply 10b (Fig. 2) and the surface roughness after a large area has been finished with mixed powder. Fig. 4(a) illustrates that the surface roughness worsens as the current level increases above 1.5 A. However, the experiments have shown that the surface roughness also worsens when the current value is too small. The following machining and electrical conditions were used to obtain the experimental data illustrated in Fig. 4-(a): Machining conditions:

(1) Electrode:	Copper
(2) Workpiece:	High-speed steel (SKH-51)
(3) Dielectric:	Kerosene mixed with silicon particles at a ratio of 20 g/ℓ
(4) Electrical conditions:	

Current peak value:	Ip = 3 A
Pulse width:	τp = 2 μs
Stop width:	τs = 2 μs
Polarity:	Electrode (+)

While a large area may be machined with low surface roughness when the mixed powder is used, as the machining area increases, the capacitance across the workpiece/electrode gap also increases. An increase in the capacitance between the electrode 4 and the workpiece 5 during machining of this large area influences the rate at which the voltage potential across the gap 7 increases (hereafter the "rise time").

Fig. 5(a) illustrates a model RC-circuit which represents the RC characteristic exhibited by the workpiece 5 and electrode 4 in Fig. 2, across the machining gap 7. As shown in Fig. 5(b), the time constant t, corresponding to the RC characteristic of the machining gap 7, is t = RC. If a resistance value R is large, such as when the current of the auxiliary power supply 10b is too small, the voltage rise time t increases. In this state, the frequency with which discharges occur decreases and machining is not stabilized, even when the powder mixture is used, resulting in more surface roughness.

In consideration of the above, the experiments indicate that a current value of approximately 1.5 A is optimal. This represents the current value provided by the auxiliary power supply. A mirror surface of the lowest surface roughness is provided at the current value of approximately 1.5 A. To provide the optimum current value, the value of the limiting resistor R2 for the auxiliary power supply must be set to an

appropriate value.

As described above, 100 to 400 V is adequate for the voltage of the auxiliary power supply 10b (Fig. 2) to keep machining stabilized. To set the current value to 1.5 A in this voltage range, the limiting resistor value R2 is maintained at R2 ≒ 100 to 300 Ω.

Fig. 18(a) shows the surface roughness at a time when R2 equals 20 Ω and Fig. 18(b) shows the surface roughness when R2 equals 200 Ω. Further it has been confirmed that the present invention extends the life of the powder material to approximately 500 hours, as compared to an ordinary life of 100 to 200 hours.

While the auxiliary power supply is used with the main power supply to superpose a high voltage in the above embodiment illustrated in Fig. 2, a similar effect can be produced in machining that does not use an auxiliary supply but still uses the mixed powder. This effect is achieved with mixed powder by using a main power supply that generates a high voltage of 200-500 V without using the auxiliary power supply. In this alternative embodiment, the current for the main power supply is limited by setting the current limiting resistor R1 at 100-300 Ω.

Another embodiment of the invention will now be described. However, prior to the description of this embodiment, the principal behind cracking will be described for single and continuous electric spark machining.

Materials having high resistance to high temperature (e.g., tungsten carbides inter-alloy WC-Co, conductive ceramics, or alloy tool steel SKD-11, SKD-51, SKH-51, etc.) are generally easily cracked during continuous electrode discharge machining. When an electric spark is emitted, the electrical condition that causes cracking may be seen. Specifically, during a single electric spark the discharge of energy is extremely large as shown in Fig. 7. A cracking range of tungsten carbide by a single spark is also shown in Fig. 7. The material must be finished under machining conditions that do not cause cracking.

In continuous electron discharge machining, however, cracking occurs even when there is a much lower discharge energy. Specific examples are shown in Fig. 8(a), 8(b) and Fig. 9(a) and 9(b).

Further, while cracking does not occur with a single electric spark when the discharging voltage Vc equals 65 V and the capacitor capacity C equals 0.1 F (tungsten carbide), cracking does occur if continuous electric sparks are applied at this voltage and capacitance. Figs. 8(a) and 8(b) illustrate this cracking condition. It is understood that when charging resistance is large and the frequency of discharge occurrence is small, the depth and thickness of cracking are small. Further, as the charging resistance decreases and the frequency of discharge increases, the depth and thickness of cracking increases.

The above results make it clear that (1) even under a condition when cracking does not occur in a single electric spark, cracking can occur on a surface subjected to continuous electronic discharge machining; and (2) as the number of electric sparks increases, cracking occurs mote easily and in a deeper and thicker form.

This may be understood from the following relationship between charging resistance R_0 and the number of sparks f as illustrated in Figs. 9(a) and 9(b):

$f = (k)/(C \cdot R_0)$; where k = a coefficient of about 0.5 to 1. Thus as R_0 decreases, f increases.

It should be noted that cracking is made deeper and wider when the number of electric sparks increases. When the charging resistance is very large, the results are close to those of a single electric spark.

The depth and thickness of cracks increases when the number of discharges increases since, as more electric sparks are generated, the ion concentration in the machining gap increases. When the ion concentration increases, it causes continuous electric sparks in an area previously subjected to discharge or in the vicinity thereof, causing a so-called focused discharge. The focused discharge greatly increases the temperature in its vicinity. This higher temperature extends to the inner regions or depths of the electrode material by the discharge heat of multiple surfaces. After the focused discharge occurs the point of discharge moves to other locations on the material due to expansion of the machining gap distance. The surface of the portion that has been heated by the focused discharge is rapidly cooled by the dielectric. Since this portion is cooled from its outer surface toward the inner portion, the surface shrinks while its inner portion remains unshrunk and at the high temperature. Hence, tensile stress develops in the surface, causing cracking.

The centralized or focused discharges have a tendency similar to the provision of a single discharge spark generated by a long pulse width. Thus, in a single electric spark, large tensile stress does not develop in the workpiece surface when the discharge energy range is small and the pulse width is short, e.g., when the capacitance C is small. This lack of tensile stress is due to the fact that the electrode's and workpiece's outer surface are subjected to small energy discharges and thus, heat is not transmitted deeply into the workpiece body.

If the material is heated only on the surface, the cracking is negligibly small since the hot portion is instantly cooled before heating the workpiece's body. The temperature difference between the surface and inner portions is compensated for before any crack develops, and the stress difference is maintained small.

The following mathematical expression applies to the pulse width τp and the current ip developed by capacitor discharge:

$$\tau p \fallingdotseq \pi\sqrt{LC}$$
$$ip \fallingdotseq (Vd-Eg)\sqrt{(C/L)}$$

$\tau p \fallingdotseq 0.7\ \mu s$, $ip \fallingdotseq 15$ A where C = 0.1 μF, L = 0.5 μH, Vd = 100 V and Eg = 25 V.

Thus, cracking may be prevented by avoiding focused discharges, which are avoided by using a discharge energy level small enough not to cause cracking in a single electric spark. The experiments have made it clear that two measures to avoid the centralized discharges are effective.

First, the invention increases the machining gap distance. This facilitates the circulation of the dielectric in the machining gap, in order to cool the discharge point and making deionization easier. By deionizing the dielectric, the invention ensures that the dielectric provides a uniform insulated layer between the electrode and workpiece. Re-establishing the insulated layer between the workpiece and electrode prevents centralized discharge. The application of a high voltage across a high impedance gap is effective to de-centralize discharge.

Moreover, increasing the concentration of the powder mixture and increasing the mixing effect can allow the machining gap distance to be increased. Thus, the machining gap distance can be further expanded by high-voltage superposition and concentrating the powder mixture.

Secondly, to facilitate the dispersion of discharge, the invention prevents any potential inclination in the machining gap to be focused on a given discharge mark. The invention prevents focusing by mixing a large amount of conductive or semiconductive (semiconductor) powder in the dielectric. Specifically, the dielectric is mixed with semiconductive or metallic powder such as Si powder (30 μm maximum), carbon powder (30 μm maximum) or Al powder (30 μm maximum or scaly).

Figs. 10(a) and 10(b) show the results of ordinary electron discharge machining on high speed steel (SKH-51) performed under the electrical conditions of a medium machining degree. This medium machining degree would ordinarily never cause cracking in a single electric spark (Ip = 10 A, τp = 16 μs, duty = 50%, i.e., τr = 16 μs). Figs. 11(a) and 11(b) show the results of machining under the identical electrical conditions with Si powder mixed at 20 g/ℓ.

These figures indicate that while cracking has occurred in the ordinary dielectric, no cracking has developed in the material machined in the dielectric mixed with the Si powder. Proof that the Si powder mixing process does not cause cracking is provided by the fact that the material is not corroded at all after it is immersed in aqua regia or the like for 50 minutes. Any material that develops cracks is easily corroded. Tungsten carbide will not develop cracking when machined within the safe, single electric spark range illustrated in Fig. 7, if the powder, such as Si powder, is added to the dielectric.

An alternative embodiment of the invention will now be described in reference to Figs. 1(a), 1(b) and 12.

In the system shown in Figs. 1(a) and 1(b), carries out machining, as explained above, in the machining gap 7 formed by the workpiece 5 and the electrode 4, wherein the gap is surrounded with the dielectric 8 mixed with the silicon powder 9.

However, in this alternative embodiment, a high-voltage superposition circuit (Fig. 12) is employed as a machining power supply. The superposition circuit includes current limiting resistors R1 and R2, a diode D, transistors TR1 and TR2, a capacitor C1, a main power supply 10a, and an auxiliary power supply 10b.

During machining, the auxiliary power supply 10b supplies a high voltage to the machining gap 7 when transistor TR1 is switched ON, in order to supply the high voltage to the machining gap 7 to generate discharges. Transistor TR2 is thereafter switched ON to cause the main power supply 10a to supply a discharge current of low energy. The superposition circuit of Fig. 12 reduces cracking by allowing the machining gap to be increased and by facilitating dispersion of the discharge.

A range in which cracking is not produced by single electron discharge machining varies according to the type of workpiece material. Fundamentally, materials having high resistance to high temperature, e.g., WC-Co and fine ceramics, are cracked by comparatively small amounts of energy. A typical example is shown in Fig. 7. For alloy tool steel, such as SKD-11, SKD-51 and SKH-51, cracking may occur at Ip of 20 A or higher and τp of 40 μs or greater.

The present invention may be embodied in other specific forms without departing from the spirit and essential attributes thereof. In addition to the above-described silicon particles, other metal particles such as for instance tungsten carbide (WC) particles may be used. Furthermore, the particles of semi-metal material

such as zirconium boride (ZrB_2), or the particles of carbonate material, or boride material, i.e., fine ceramic material may be used for formation of surface layers.

The machining solution is not always limited to mineral oil. That is, silicon oil or water (distilled water) may be employed as long as electric discharges will occur in it. The surface layer can be formed even on a ceramic material which is not electrically conductive. In this case, only the target surface of the ceramic material is made electrically conductive by electroless plating or spectacle reaction.

The surface layer may be formed by using a material which is not electrically conductive. In this case, the material is formed into particles as fine as possible, and the material particles thus formed are mixed with electrically conductive particles. The above-described operation is carried out by using the particles thus prepared. The non-conductive material can be alumina (Al_2O_3) for instance.

The same effects can be obtained according to the following method: Disposing particles of material, such as silicon for formation of a surface layer, between the electrode and the workpiece which are held in air, and inducing electric discharges therebetween.

In the above-described various embodiments of the invention, a key point is to dispose a sufficient number of material particles such as silicon particles for formation of a surface layer in the inter-electrode space. This makes the inter-electrode distance larger than the ordinary one, to allow the presence of the material particles such as silicon particles in an amount more than the amount of material removed from the workpiece per electric discharge near the discharge point.

As was described above, in the method of the invention, a material for formation of a surface layer on a workpiece is provided in the form of fine particles in the inter-electrode gap. Under this condition, electric discharges are induced therein. Therefore, the resultant surface layer is higher in corrosion resistance and in adhesion than what is formed with an ordinary discharge machining electrode. In the conventional high temperature nitriding method or CVD, the surface treatment is carried out at temperatures around 900°, and therefore the workpiece is liable to be strained or softened; and if the temperature is decreased, then the surface layer formed is liable to peel off. On the other hand, in the method of the invention, the workpiece will not be strained nor softened. Thus, the method of the invention may be suitably employed for surface treatment of a variety of workpieces.

According to another aspect of the invention, the material particles between the electrode and the workpiece are moved during electric discharge, which prevents the difficulty that the material particles such as silicon particles stick to one another, resulting in lowering the roughness of the surface layer formed on the workpiece.

Claims

1. An electric discharge machining apparatus for farming a surface layer on a workpiece, comprising:
   an electrode positioned near the workpiece, wherein a machining gap is formed between the electrode and the workpiece, said machining gap containing a dielectric mixture, which includes one of a metallic and submetallic powder,
   a main power supply circuit for supplying a low voltage to the machining gap, and
   a high-voltage superposition circuit for superposing a high voltage on said main circuit, in order to generate an electric spark in the machining gap and in the dielectric mixture.

2. An electric discharge machining apparatus according to claim 1, further comprising:
   a first current limiting resistor, connected between the high-voltage superposition circuit and the electrode, for limiting the current flow from the high-voltage superposition circuit, and
   a second current limiting resistor, connected between the main power source and the electrode, for limiting the current flow from the main power source.

3. An electric discharge machining apparatus according to claim 1, wherein an output voltage of the high-voltage superposition circuit is between 100 and 400 volts.

4. An electric discharge machining apparatus according to claim 2, wherein an output voltage of the high-voltage superposition circuit is between 100 and 400 volts, and a resistance of the first and second current limiting resistance circuit is between 10 and 20 ohms, and 100 and 300 ohms, respectively.

5. An electric discharge machining apparatus according to claim 1, wherein the high-voltage superposition circuit outputs a high voltage between 200 and 500 volts.

6. An electric discharge machining apparatus according to claim 2, further comprising:
a first transistor circuit, connected in series with the first current limiting resistor, for turning the high-voltage superposition circuit ON and OFF, and
a second transistor circuit, connected in series with the second current limiting resistor, for turning the main power supply ON and OFF.

7. An electric discharge machining apparatus according to claim 6, further comprising:
a controller for turning said first transistor circuit ON, in order for said high-voltage superposition circuit to produce an electric spark across said machining gap, and for turning said second transistor circuit ON, in order for said main power supply to supply a discharge current across said machining gap, wherein a duration of said discharge current lasts for several micro-seconds and is determined by the resistance of said second resistor.

8. An electric discharge machining apparatus according to claim 1, further comprising current limiting means for limiting a current flow through said electrode to approximately 1.5 amps, in order to minimize surface roughness on the workpiece.

9. An electric discharge machining apparatus according to claim 1, further comprising:
a controller for turning said high-voltage superposition circuit ON to produce an electric potential across said machining gap, and for turning said main power supply ON to supply a discharge current across said machining gap, wherein a duration of said discharge current equals several micro-seconds.

FIG. 1(a)

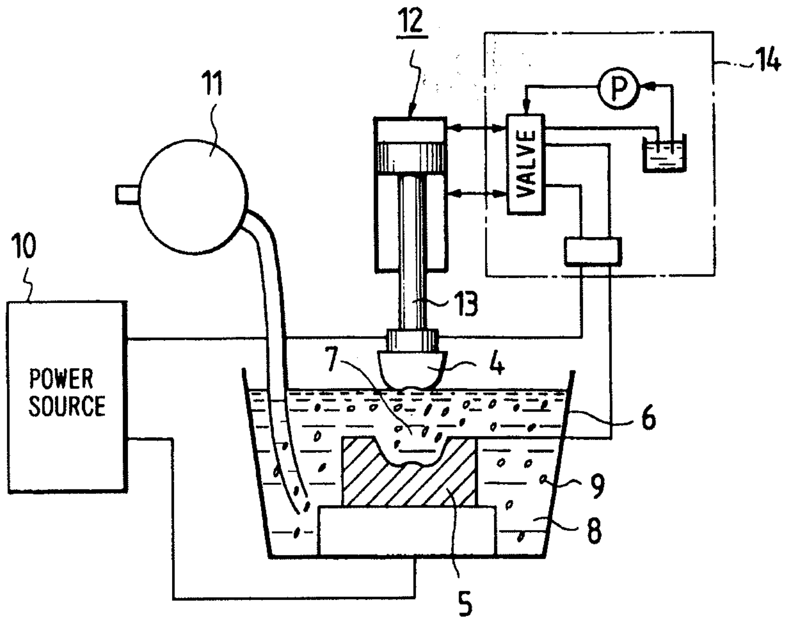

12
11
14
P
VALVE
10
POWER
SOURCE
13
7
4
6
9
8
5

FIG. 1(b)

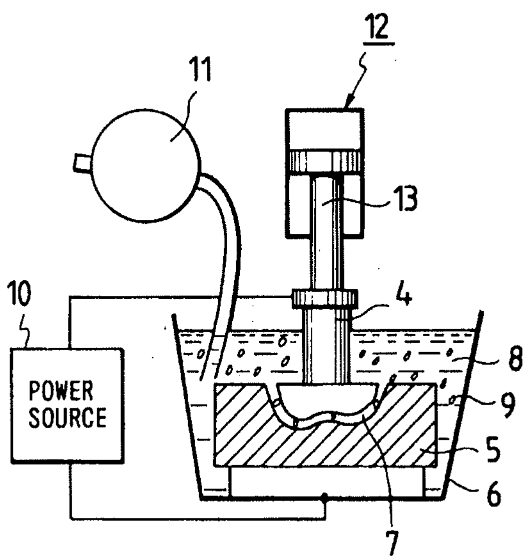

12
11
13
10
4
POWER
SOURCE
8
9
5
6
7

FIG. 2

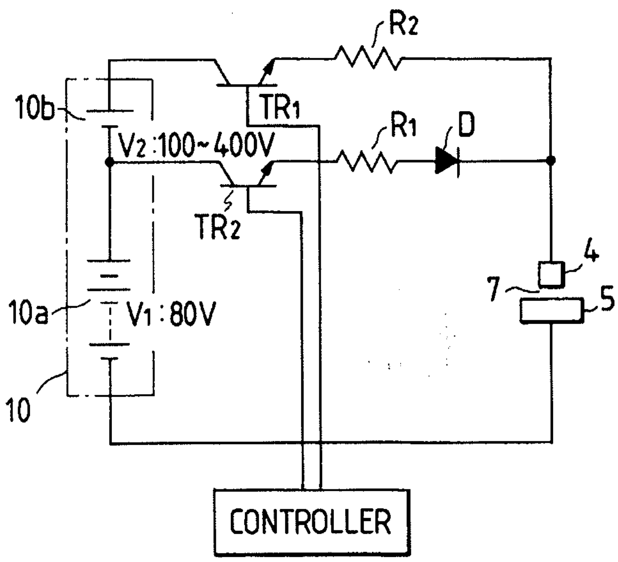


FIG. 3(a)

FIG. 3(b)

FIG. 3(c)

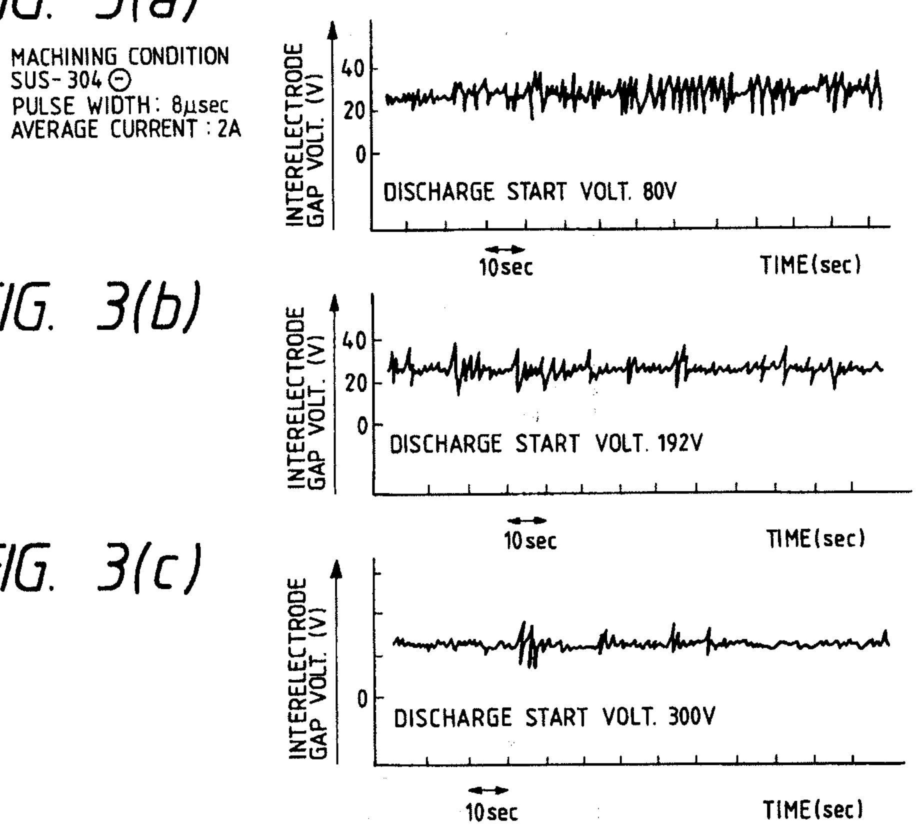


FIG. 4(a)

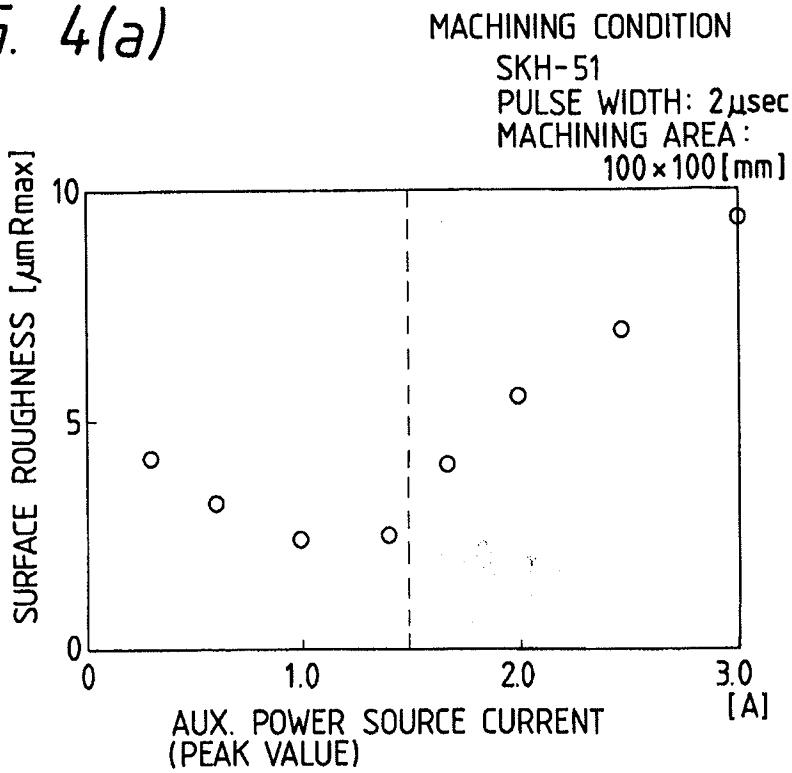


FIG. 4(b)

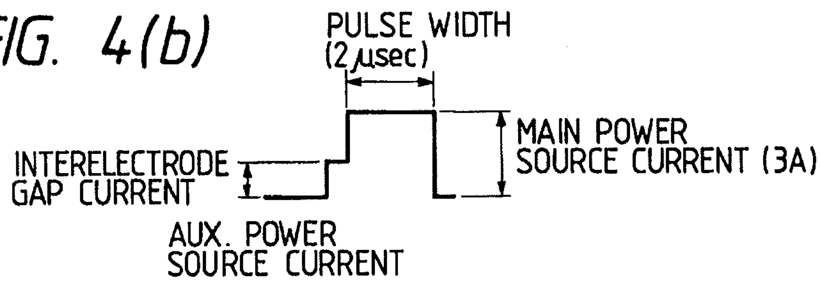


FIG. 5(a)

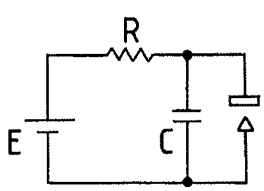


FIG. 5(b)

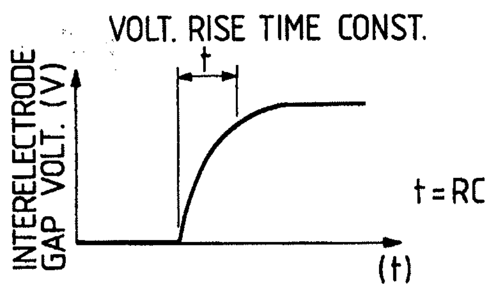


FIG. 6(a)

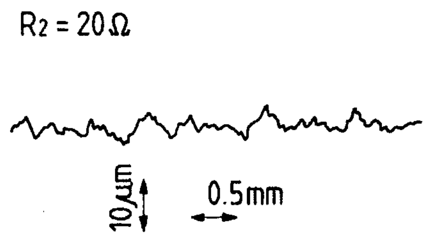


FIG. 6(b)

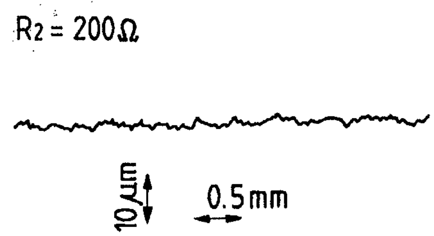


FIG. 7

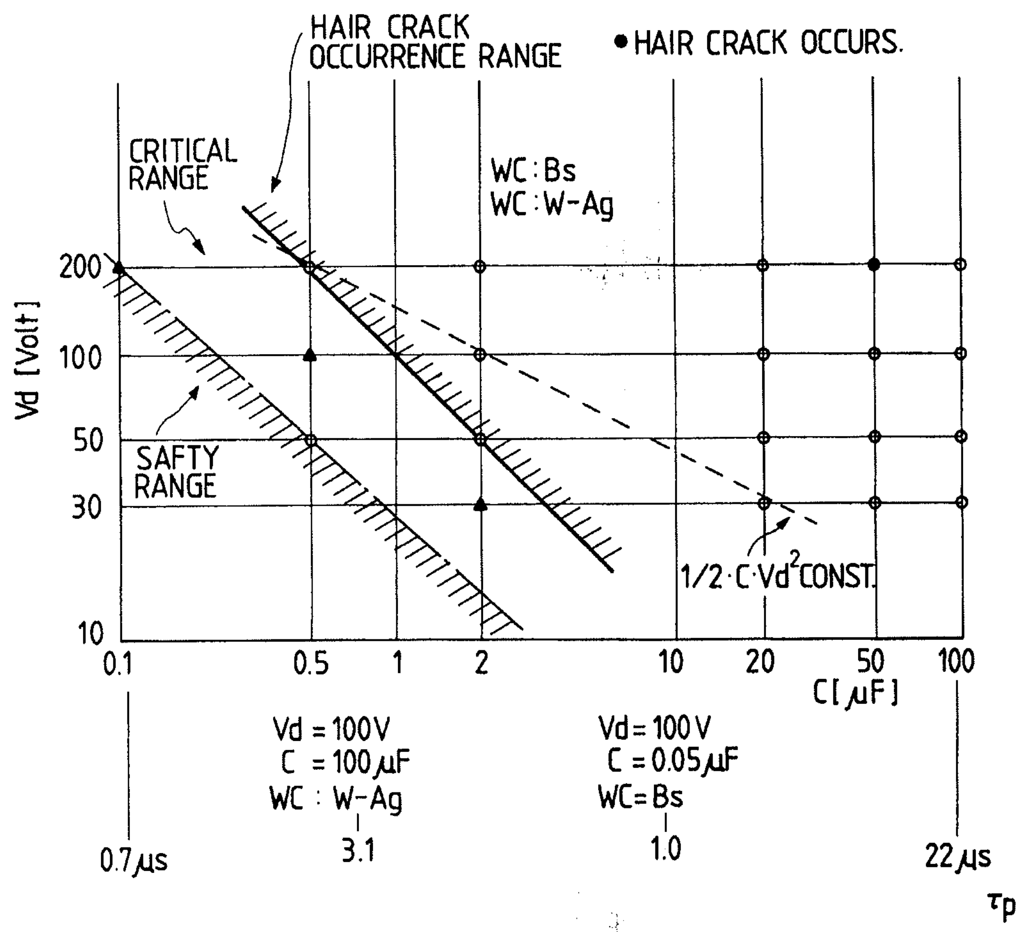


FIG. 8(a)

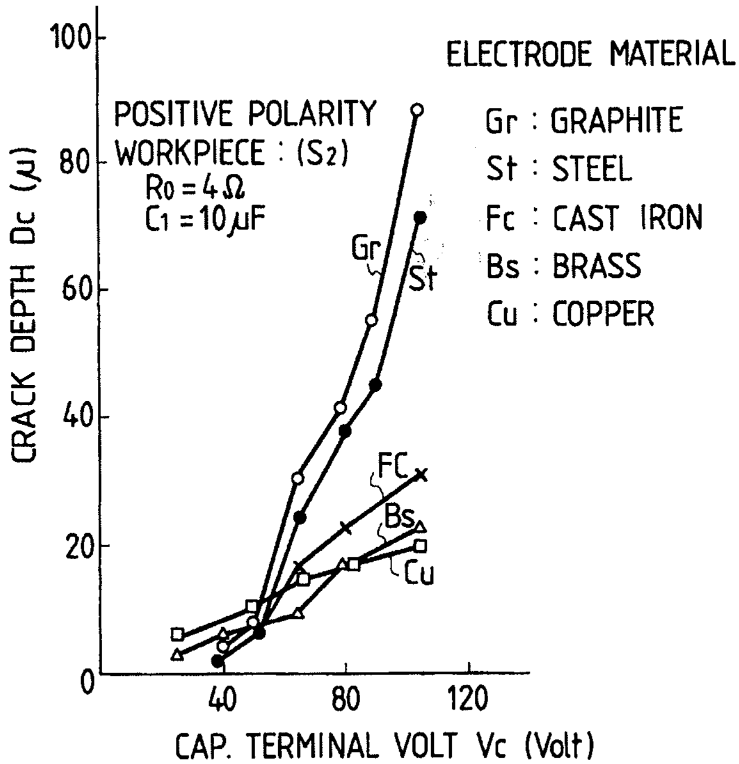
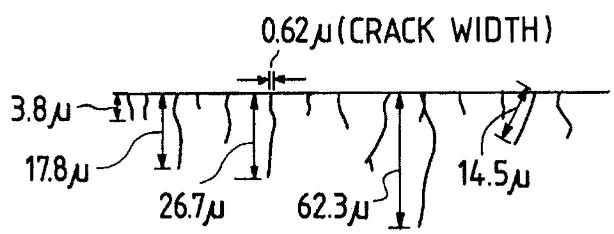


FIG. 8(b)



TOOL ELECTRODE : FC. WORKPIECE : S_2
$R_0 = 4\Omega$, $V_c = 65V$, $C_1 = 0.1\mu F$
CRACK CONDITION (CROSS-SECTION)

FIG. 9(a)

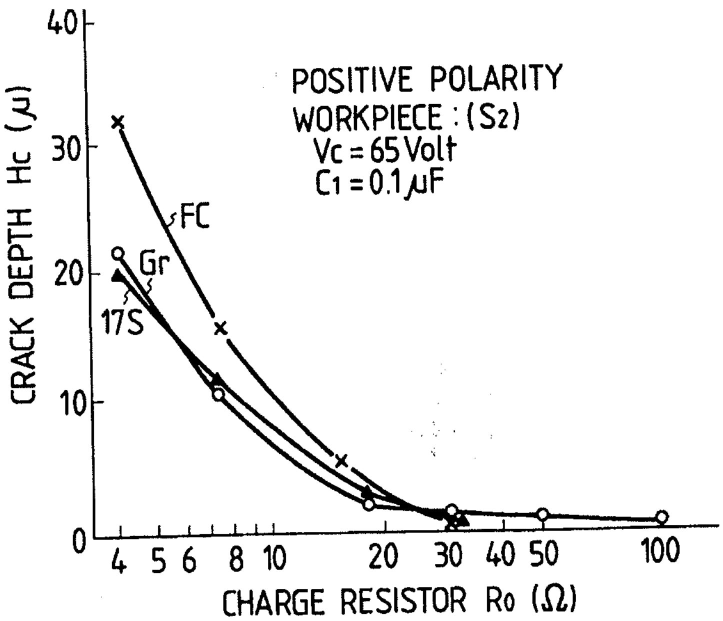

POSITIVE POLARITY
WORKPIECE : (S2)
Vc = 65 Volt
C1 = 0.1 μF
FC
Gr
17S
CRACK DEPTH Hc (μ)
40
30
20
10
0
4 5 6 8 10 20 30 40 50 100
CHARGE RESISTOR Ro (Ω)

FIG. 9(b)

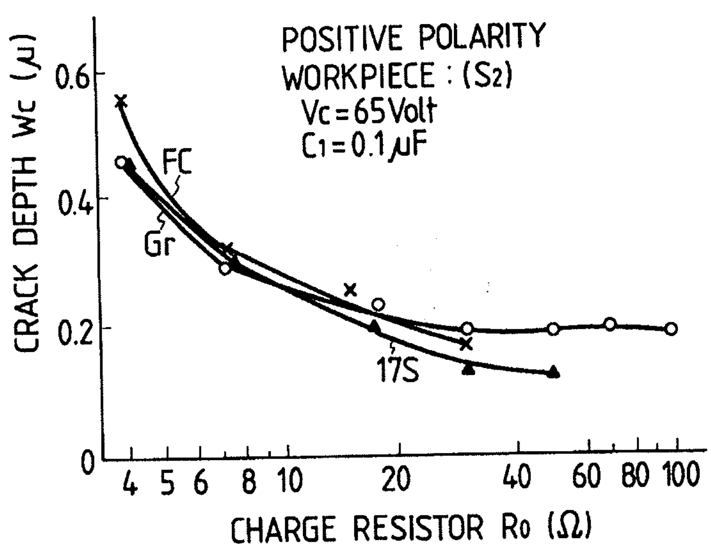

POSITIVE POLARITY
WORKPIECE : (S2)
Vc = 65 Volt
C1 = 0.1 μF
FC
Gr
17S
CRACK DEPTH Wc (μ)
0.6
0.4
0.2
0
4 5 6 8 10 20 40 60 80 100
CHARGE RESISTOR Ro (Ω)

FIG. 10(a)

x500

FIG. 10(b)

x200

$I_p = 10A$, $\tau_p = 16\mu s$, $\tau_r = 16\mu s$

SKH-51

FIG. 11(a)

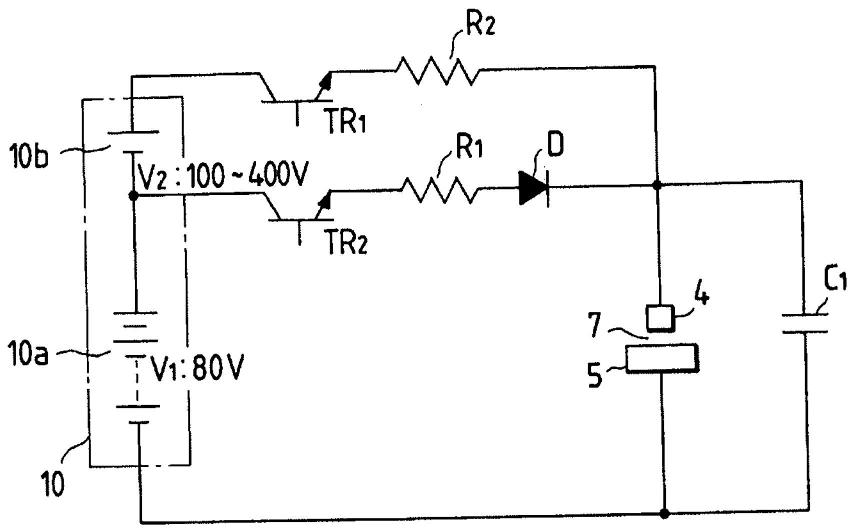
x500

FIG. 11(b)

x 200

$I_p = 10A$, $\tau_p = 16 \mu s$, $\tau_r = 16 \mu s$
SKH-51

FIG. 12



European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 12 1827

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	US-A-4 443 682 (KUANG-TA HO) 17 April 1984 * column 1, line 56 - column 2, line 42 * * column 3, line 1 - line 57 * * abstract; claims 1-12; figures 1-3 *	1-9	B23H1/00 B23H1/08 B23H1/02
Y	GB-A-1 121 923 (GENERAL MOTORS CORPORATION) 31 July 1968 * page 1, line 15 - line 36 * * page 2, line 77 - line 119 * * claims 1-6; figure 1 *	1-9	
A	WO-A-8 000 669 (ATELIERS DE CHARMILLES SA) 17 April 1980 * page 4, line 1 - page 6, line 15 * * page 10, line 14 - page 11, line 12 * * abstract; claims 1-4; figures 1-3 *	1-9	
A	US-A-3 509 305 (R.B. BERTOLASI) 28 April 1970 * column 1, line 10 - line 37 * * column 1, line 67 - column 2, line 39 * * column 2, line 70 - column 3, line 17 * * column 3, line 34 - line 66 * * abstract; claims 1-10; figures 1-3 *	1-9	TECHNICAL FIELDS SEARCHED (Int. Cl.5) B23H C21D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	31 MARCH 1993	HAEGEMAN M.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P0401)